HISTOLOGY OF THE EAR

The paired ears are specialized organs adapted for…

1. **The reception and transduction of vibration into sounds (audition)**
2. **Detection of position of the head (and body) relative to gravity**
3. **Detection of motion and acceleration of the head**

adapted across species to meet environmental needs

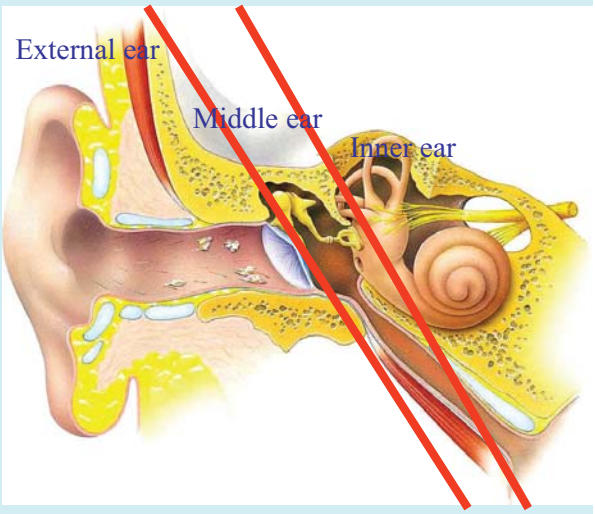
Human

- **unequalled in the ability to detect rapidly articulated speech**
- **well adapted for the localization of sounds in space**

(surpassed only by echolocators).

The Ear is traditionally divided into 3 parts

1. **EXTERNAL EAR =**
   - **Auricle (pinnae)**
   - **External Auditory Meatus**
   - **Tympanic Membrane**
2. **MIDDLE EAR =**
   - **Tympanic Cavity**
   - **Ossicles**
   - **Eustachian Tube**
3. **INNER EAR =**
   - **Bony Labyrinth**
   - **Membranous Labyrinth**



EXTERNAL EAR:

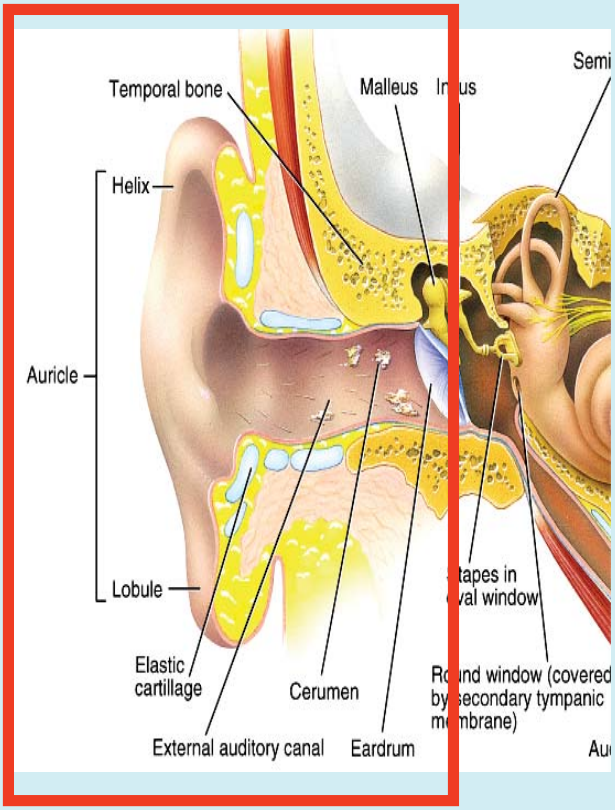
Collects sound vibrations – directs them towards the sensory transducers. 3 parts

1. AURICLE:

- **irregular plate of elastic cartilage**
- **covered by thin skin w/**
- **hair follicles & sebaceous glands.**

In lower animals striated muscle is present for directing this structure toward the source of sound.

involved in the localization of sound in space.



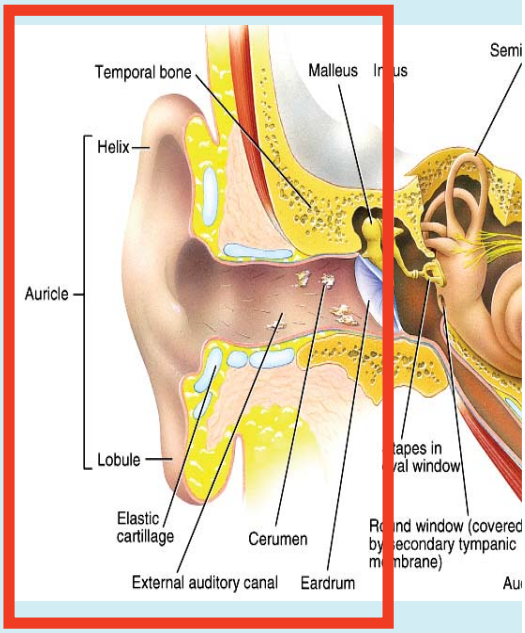
2. EXTERNAL AUDITORY MEATUS:

2.5 cm tube connected the temporal bone

- **outer 1/3 -- elastic cartilage continuous with the cartilage of the auricle.**
- **inner 2/3 is formed by the temporal bone**

lined by thin skin

- **w/ modified apocrine sweat glands called CERUMINOUS GLANDS that secrete a brown waxy protective secretion = CERUMEN**



3. TYMPANIC MEMBRANE (EARDRUM):

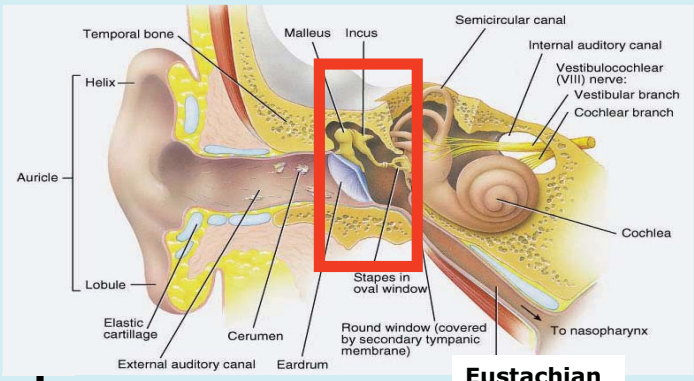
closes the innermost aspects of the external meatus

consists of 2 layers of collagen (radial and circular) covered on:

- **the meatus side by a layer of very thin skin**
- **the inside by a simple squamous epithelium**

sound pressure wave displace this membrane and its vibration is transmitted to the middle ear bones.

MIDDLE EAR:



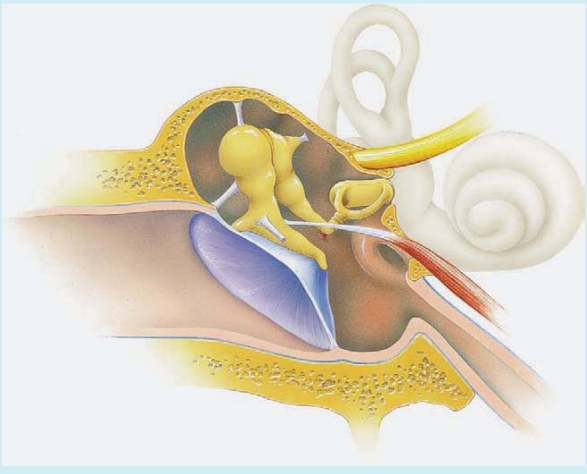
transduces sound pressure waves into mechanical displacement of inner ear structures. 3 major components

1. TYMPANIC CAVITY:

box-like air filled cavity deep to the external meatus.

- **lateral wall =tympanic membrane**
- **medial wall =the bony labyrinth of the inner ear**

acts as a resonance chamber.



Lined with simple squamous epithelium with a thin lamina propria

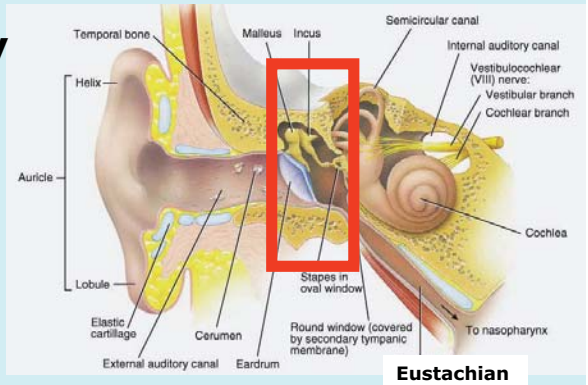
2. EUSTACHIAN TUBE

4 cm cartilaginous tube

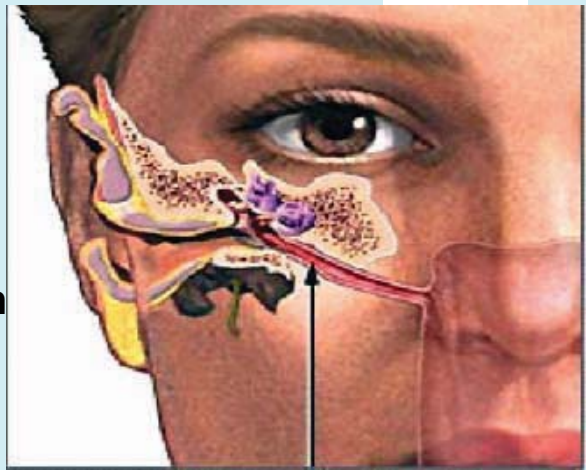
- connects the tympanic cavity with the nasopharynx.

- equalizes pressure between the outside air and the middle ear cavity.

-- cartilage, covered by a pseudostratified columnar ciliated epithelium

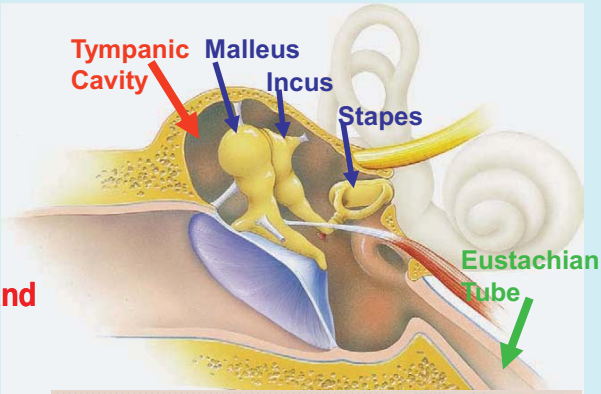


Eustachian tube



Clinically Important:

- allows direct access to the middle ear cavity and is thus a common route for infection (Otitis Media).



3. OSSICLES:

Tympanic Cavity is spanned by a series of three small bones called the Auditory Ossicle.

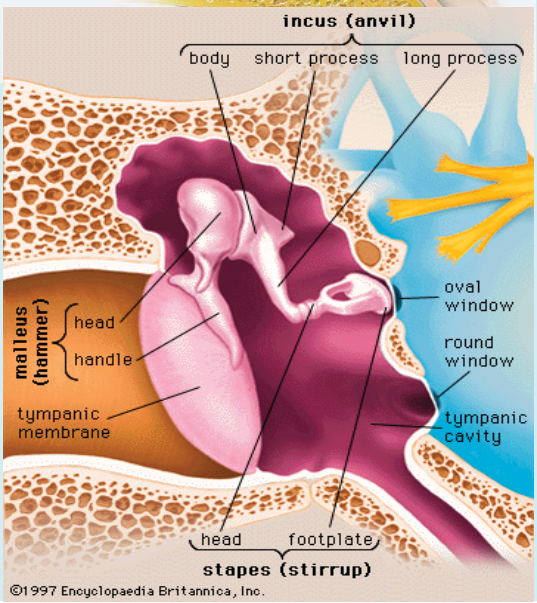
From external inward these are the Malleus, Incus, and STAPES.

Malleus - attached to the tympanic membrane at one end and the Incus at the other.

Incus - suspended between the Maleus and the Stapes

Stapes - attached to the Incus at one end and a small oval membrane-covered opening in the medial wall of the tympanic cavity called the OVAL WINDOW at the other.

The Malleus and the Incus are suspended by small ligaments from the roof of the tympanic cavity



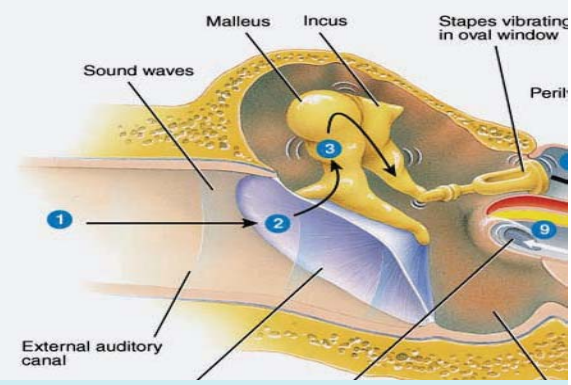
ossicles acts like a lever system to transmit the movements of the tympanic membrane to the sensory apparatus of the inner ear.

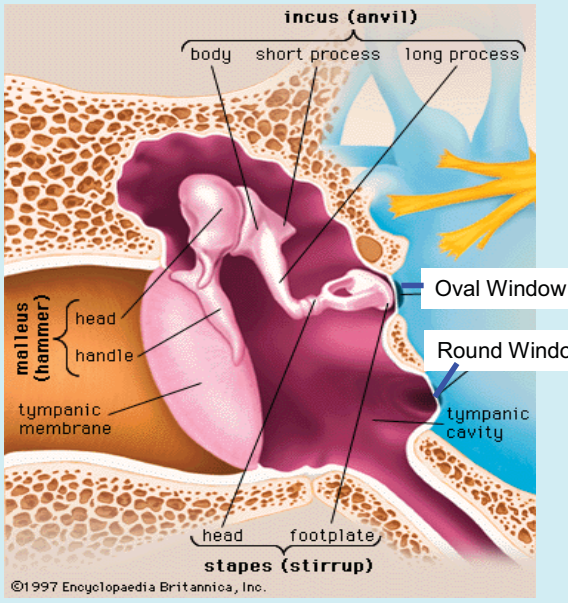
- decrease the amplitude
- but increase the force of the mechanical displacements of the tympanic membrane = "IMPEDANCE MATCHING".

The chambers of the inner ear are fluid filled - not compressible

- an outlet must exist for the forces transmitted by the ossicles to the Oval Window.
  - This function is served by a second opening in the medial wall of the tympanic cavity called the ROUND WINDOW

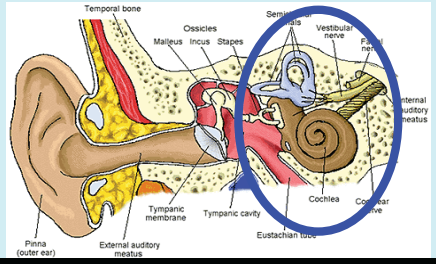
covered by fibrous membrane called the Secondary Tympanic Membrane





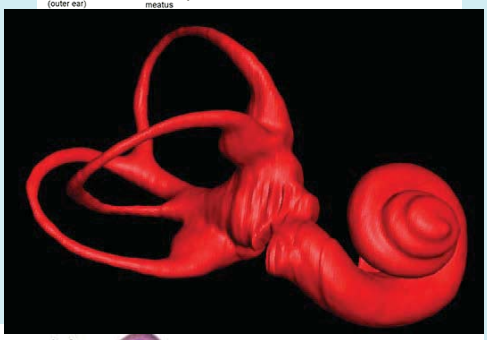
INNER EAR:

houses the vibration and motion/pressure - sensitive receptors for hearing and vestibular sensation.



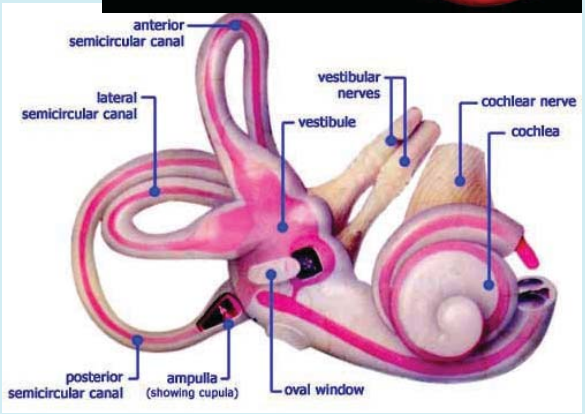
BONY LABYRINTH

a series of bony channels consisting of 5 parts:



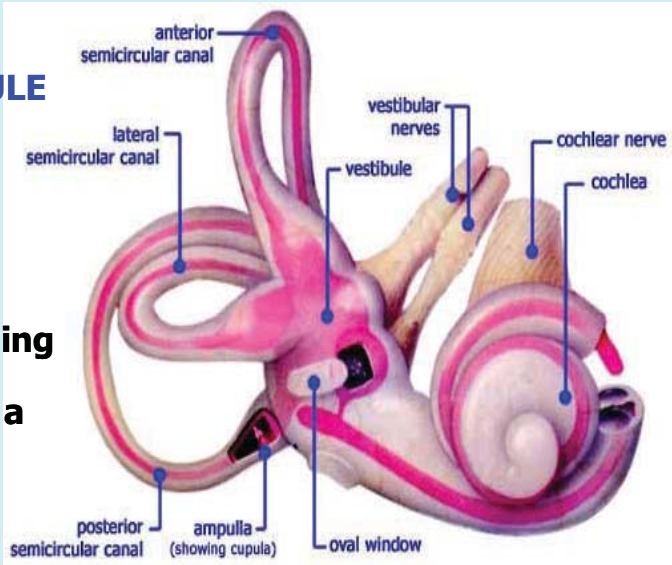
1. VESTIBULE:

large irregular, central cavity whose lateral wall contain two membrane covered openings = "Oval" and "Round" windows which lead into the adjacent cochlear canal.



EXTENDING OUT FROM THE VESTIBULE ARE 4 BONY TUBE-LIKE CHAMBERS

- 1 Coclear canal
- 3 Semicircular canals

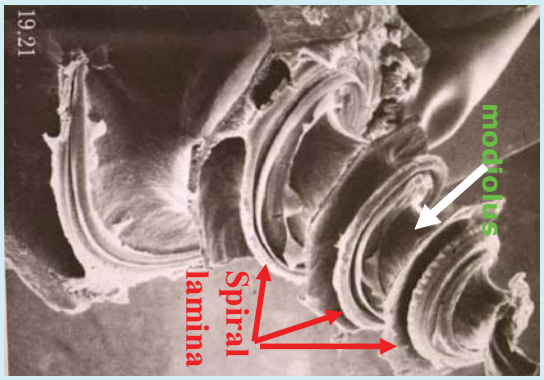


2. COCHLEAR CANAL:

Cochlear canal - anteriorly extending tube (35mm) that spirals like a snails shell for 2 3/4 turns around a central bony axis called the MODIOLUS.

-- Extending laterally from the modiolus like the threads of a screw is a thin bony ridge called the SPIRAL LAMINA

-- spaces within the bony modiolus house blood vessels and the cell bodies and processes of the Spiral Ganglion cells and the Acoustic Branch of the VIII cranial nerve

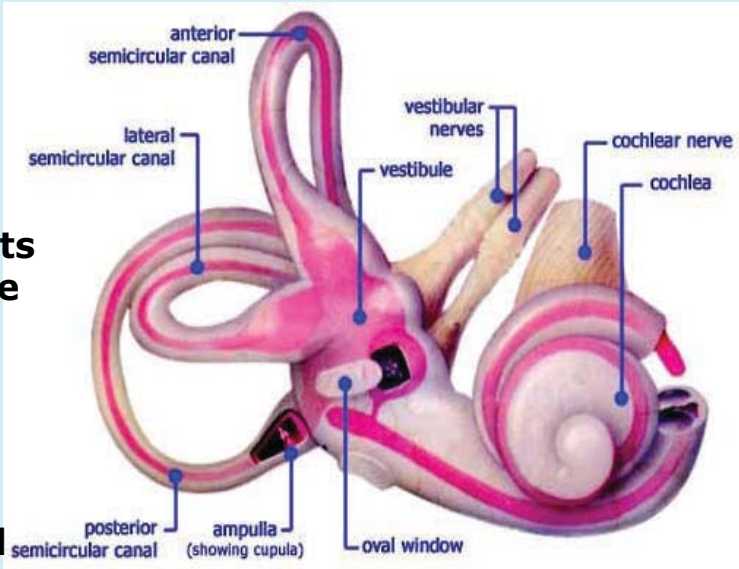


3- SEMICIRCULAR CANALS

anterior - posterior - lateral (superior)

- extend posteriorly from the vestibule. (armchair)

Each canal has a dilation at its connection with the vestibule called the AMPULLA



The Bony Labyrinth is

- filled with a clear fluid called PERILYMPH
- which resembles extracellular fluid (and CSF) in composition (high Na+, low K+)

MEMBRANOUS LABYRINTH

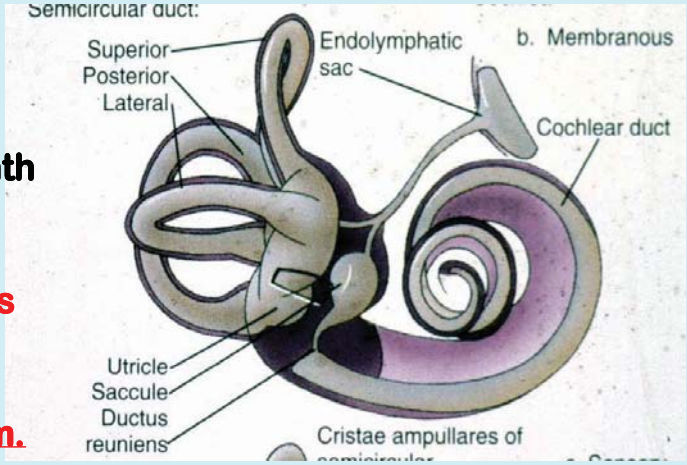
The Channels of the Bony Labyrinth house membranous ducts. which contain the specialized sensory organs for hearing and vestibular sensation termed the membranous labyrinth.

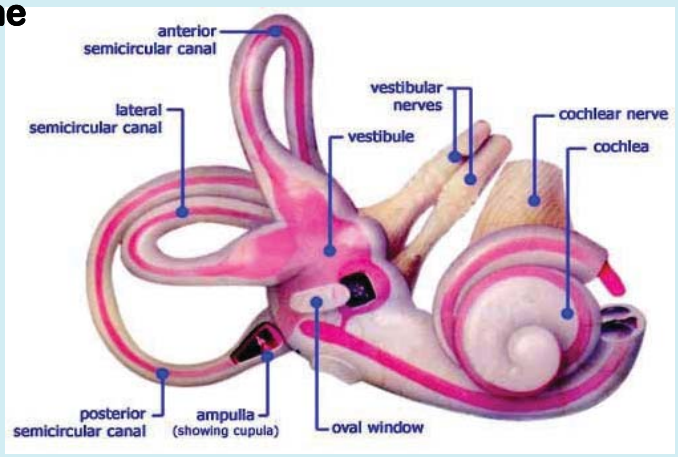
delicate connective tissue , lined with a simple squamous epithelium.

The ducts are suspended within the perilymph of the bony labyrinth by thin strands of connective tissue containing blood vessels.

The shape of the membranous labyrinth follows that of the Bony Labyrinth

except the large bony vestibule region is occupied by two membranous sacs called the UTRICLE and the SACCULE





The components of the Membranous Labyrinth can be divided into those associated with:

1. VESTIBULAR SENSE:

3 Semicircular Ducts + Utricle and Saccule .

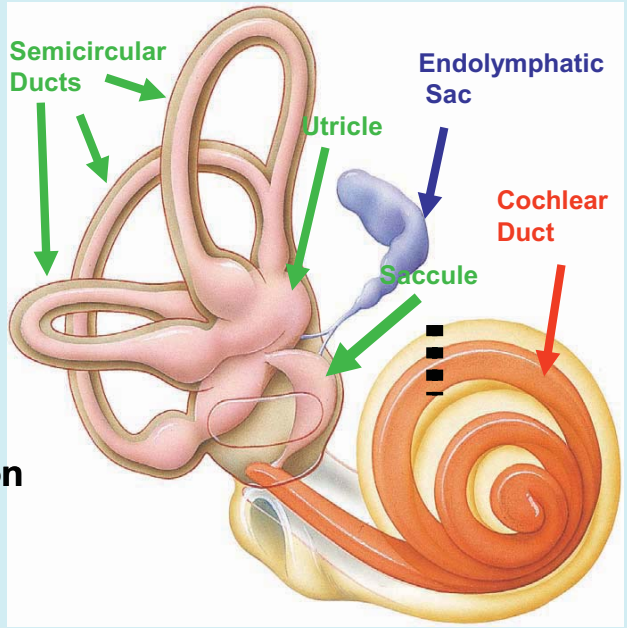
2. AUDITION: Cochlear (Auditory) Duct

membranous ducts are all

- interconnected and share a common fluid medium ENDOLYMPH
- similar in composition to intracellular fluid (K+, Na+)

Endolymph: drains into a small duct arising from the Utricle and Saccule = ENDOLYMPHATIC DUCT

- terminates in just above the dura of the CNS. Endolymph is filtered back into the CSF through this



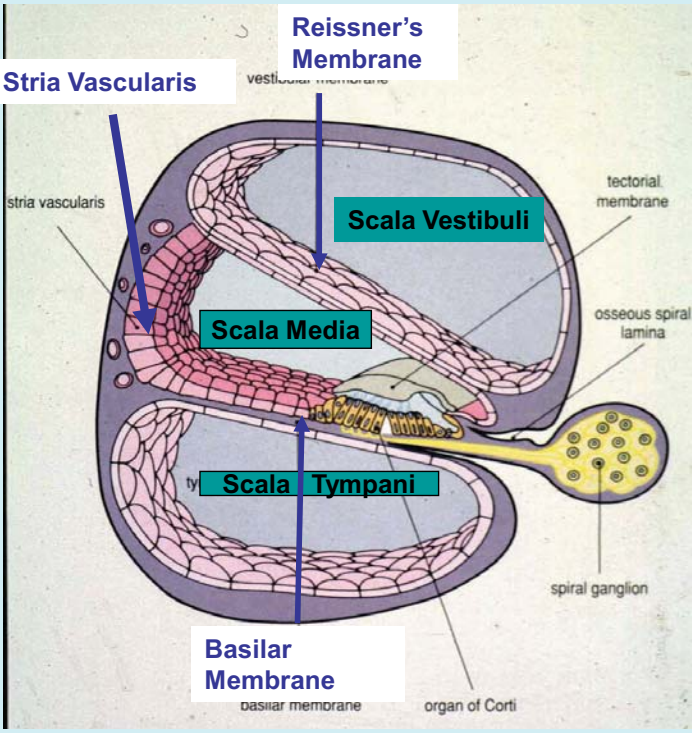
AUDITORY SENSORY APPARATUS

COCHLEAR DUCT- situated in the Cochlear Canal of the Bony Labyrinth

suspended medially within the Cochlear Canal and follows its coiled path ending as a blind sac at the apex of the Cochlear Canal

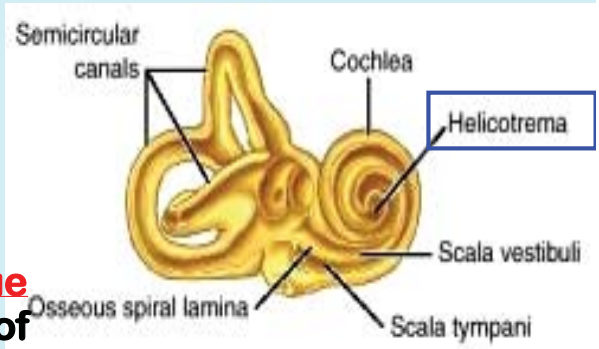
roughly triangular in transverse section - divides the Cochlear Canal into three partitions:

- **SCALA VESTIBULI**
- **SCALA MEDIA (COCHLEA)**
- **SCALA TYMPANI**



The Scala Vestibuli and Scala Tympani

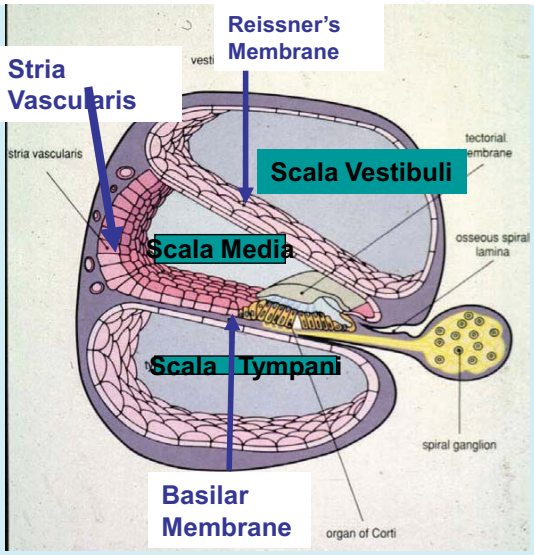
- **perilymph filled spaces lying on either side of the Cochlea.**
- **lined with a thin connective tissue continuous with the periosteum of the Cochlear Canal.**



-- **The scala vestibuli + scala tympani communicate across a small aperture at the apex of the Cochlear Canal known as the HELICOTREMA.**

-- **The central partition of the Cochlear Canal is the COCHLEA whose apex points toward the Bony Modiolus.**

- filled with endolymph.



The Walls of the Cochlear Duct are formed as follows:

A. **Roof =** **REISSNER'S (VESTIBULAR) MEMBRANE**

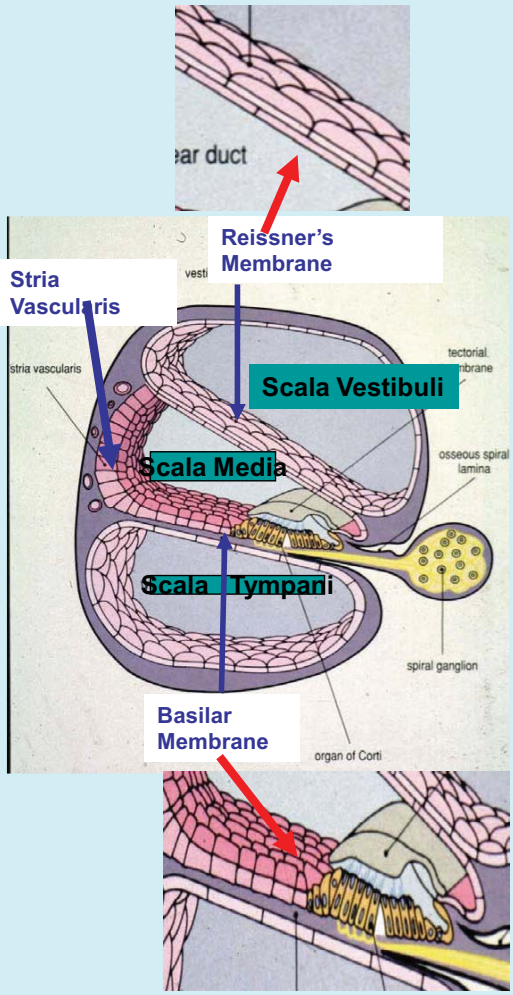
-- 2 layers of **simple squamous epithelium** separated by a basement membrane.

B. **lateral wall** - a thin layer of connective tissue applied to the walls of the Cochlear Canal and covered by a **highly vascular** epithelium called the **STRIA VASCULARIS**.

-- These vessels are thought to be the **source of endolymph**.

C. **Floor = BASILAR MEMBRANE**

- composed of amorphous ground substance infiltrated with **transversely oriented filaments** whose lower surface is covered by a **columnar epithelium.**
- Supports the auditory apparatus, the **ORGAN OF CORTI** which is anchored to the Bony Labyrinth by the **SPIRAL LIGAMENT** at one end and the **OSSEOUS SPIRAL LAMINA** at the other.



The basilar membrane is a long structure that has different properties (width, stiffness) at different points along its length.

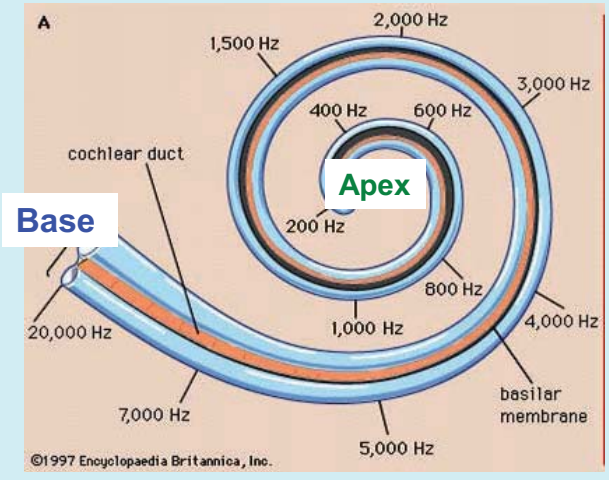
These parameters of the membrane at a given point along its length determine its characteristic frequency (CF), the frequency at which it is most sensitive tosound vibrations.

The Basilar membrane is

- widest (0.42–0.65 mm) and least taut at the apex of the cochlea,
- narrowest (0.08–0.16 mm) and most taut at the base.

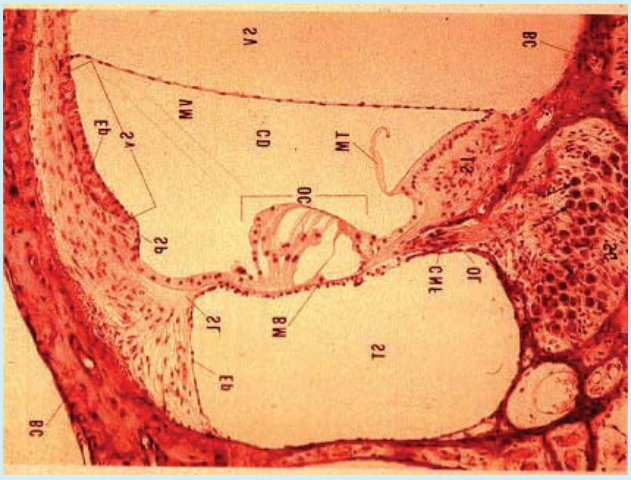
High-frequency sounds
localize near the **base** of the cochlea (near the round and oval windows)

Low-frequency sounds
localize near the **apex** (near the Helicotrema).



THE ORGAN OF CORTI:

This is a complex organ of hearing which rest atop the Basilar Membrane.

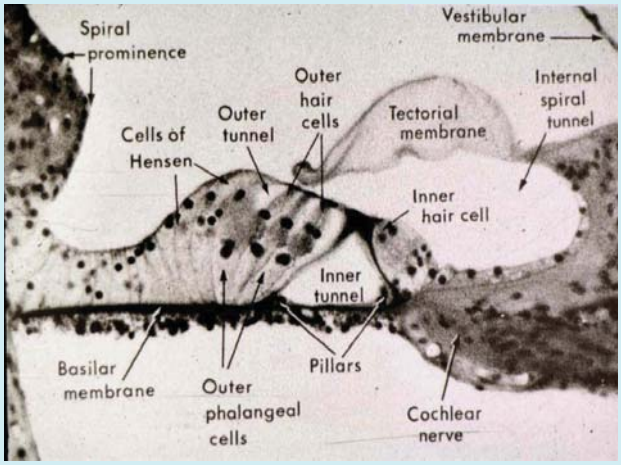


The functional elements of the organ of corti are:

A. TUNNEL OF CORTI:

- **A triangular shaped tunnel located midway across the the basilar membrane**
- **running the entire length of the Cochlea.**

The base of the tunnel is formed by the Basilar Membrane and the walls are formed by Supporting cells



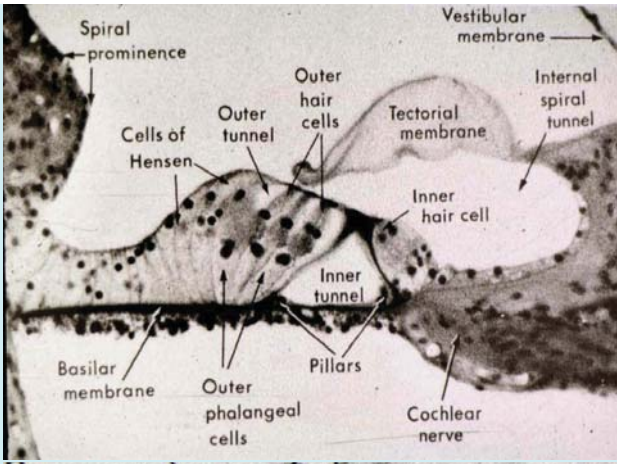
B. Two major types of columnar supporting cells

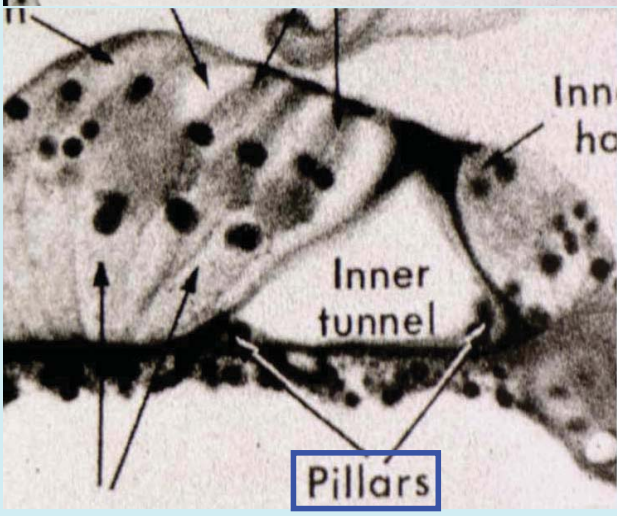
1. PILLAR CELLS:

-- Cone shaped columnar cells with basally placed nuclei.

-- rigid cells due to numerous cytoplasmic microtubules

-- These cells form the walls of the Tunnel of Corti





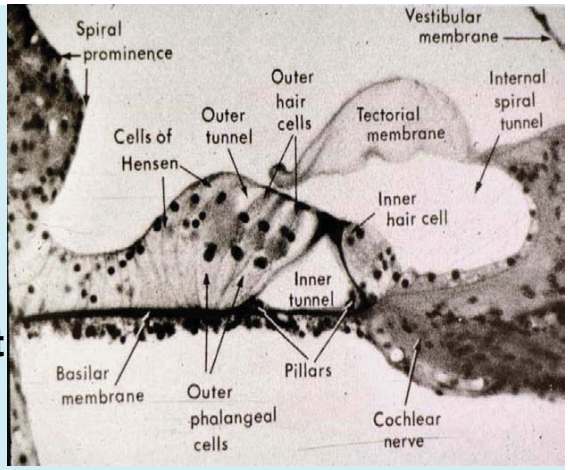
2. PHALANGEAL CELLS:

-- Tall columnar cells that support the base of the sensory hair cells

the apical surface of these cells project a slender cytoplasmic process called the Phalanx which extends to the free surface of the organ of corti alongside the hair cells to terminate in a plate-like expansion

The Phalanx envelopes the apical surface of the sensory hair cells.

The lateral borders of adjacent phalanxes have well developed tight junctions.



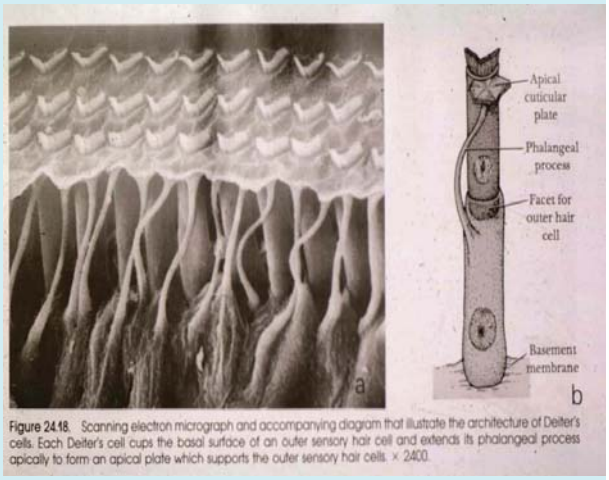


Figure 24.18 Scanning electron micrograph and accompanying diagram that illustrate the architecture of Deiter's cells. Each Deiter's cell cups the basal surface of an outer sensory hair cell and extends its phalangeal process apically to form an apical plate which supports the outer sensory hair cells. × 2400.

C. Two types of Sensory Hair Cells

1. INNER HAIR CELLS:

-- Short goblet shaped cells, numbering about 3500,

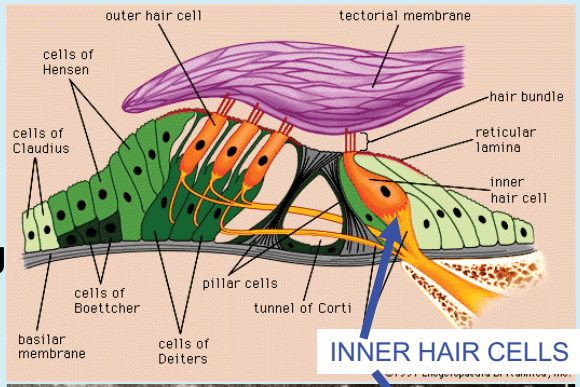
-- arranged in a single row along the length of the cochlea.

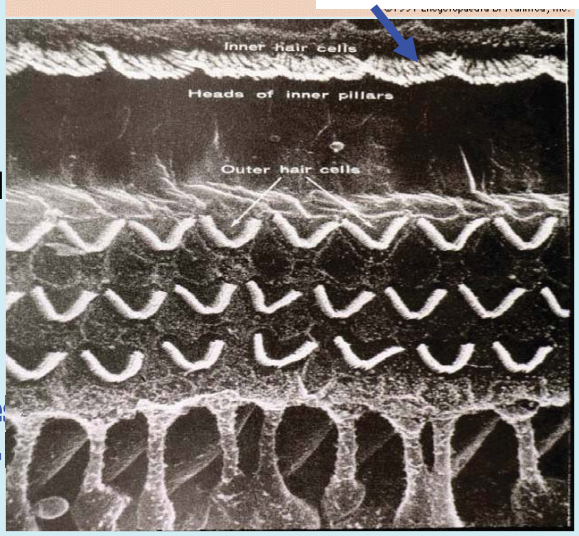
50-70 specialized microvilli known as "stereocilia" extend from the apical surface of each cell.

These cells are sensitive to small changes in sound "intensity".

recieve a dense innervation by fibers of the 8th nerve

– each hair cells receiving synapse from an average of 20 nerve fibers.





2. **OUTER HAIR CELLS**
   -- cylindrical columnar cells, with basally located nuclei, numbering about 20,000

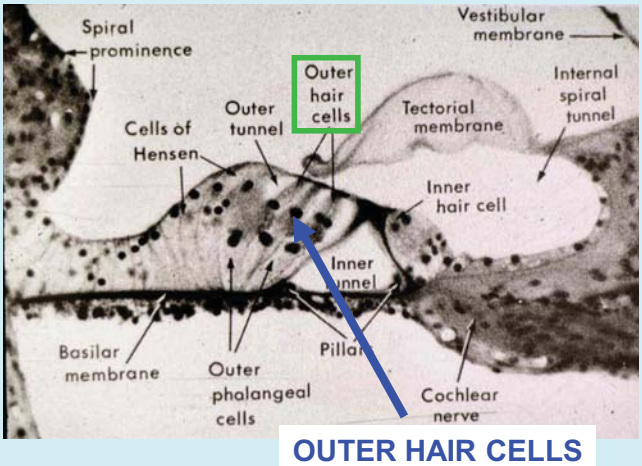
   -- form 3 rows extending the length of the cochlea.

apical surface has 100 - 300 stereocilia of uneven length arranged in the shape of a " W "

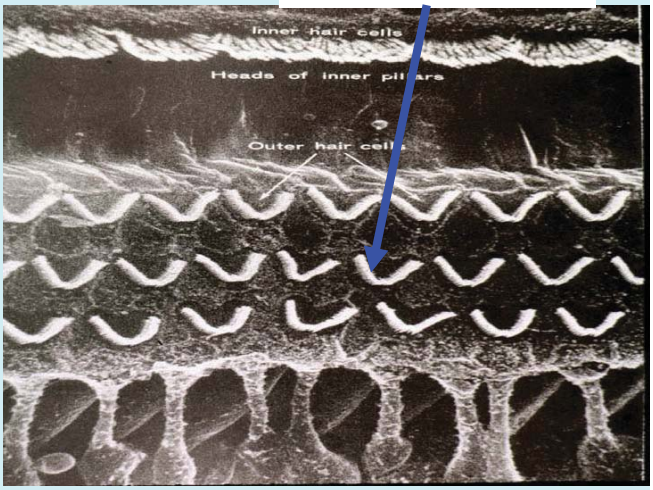
The tips of the tallest stereocilia are embedded in the tectorial membrane.

Outer Hair Cells:

- respond best to "low intensity" sounds
- have relatively few neuronal connections.



OUTER HAIR CELLS



A single 8th nerve fiber innervates and average of 50 outer hair cells.

THE BASE OF BOTH HAIR CELL TYPES SERVE AS THEIR SYNAPTIC SURFACE.

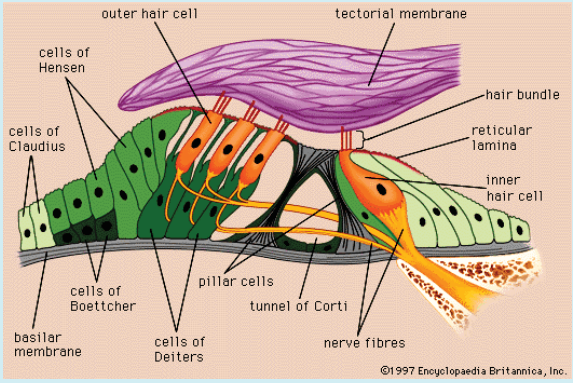
EACH MAKES NUMEROUS CONTACTS WITH THE DENDRITIC PROCESSES OF THE SPIRAL GANGLION CELLS OF THE VIIITH CRANIAL NERVE .

D. TECTORIAL MEMBRANE:

-- thin gelatinous membrane composed of a "Keratin-like" protein.

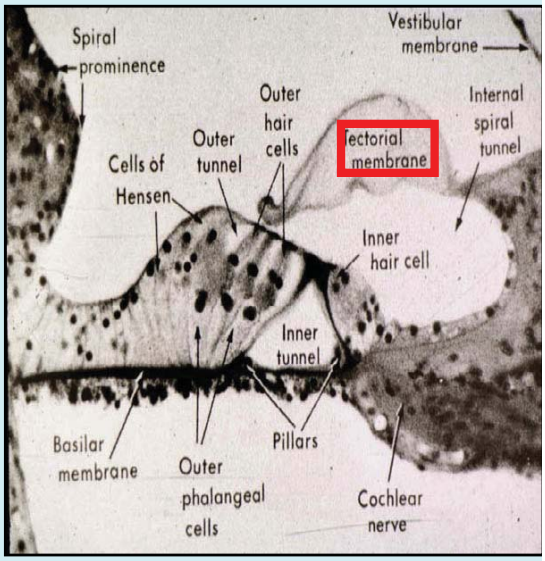
-- Extends from the spiral laminae to form the superior surface of the organ of corti.

-- thought to originate as a secretion of the cells of the spiral laminae.



THE TIP OF THE HAIR CELL STEREOCILIA ARE EMBEDDED IN THE TECTORIAL MEMBRANE.

THE SHEERING OF THIS MEMBRANE WITH RESPECT TO THE CELL BODIES OF THE SENSORY HAIR CELLS TRIGGERS ELECTRICAL IMPULSES IN THESE CELLS AND RESULTS IN SOUND TRANSDUCTION.



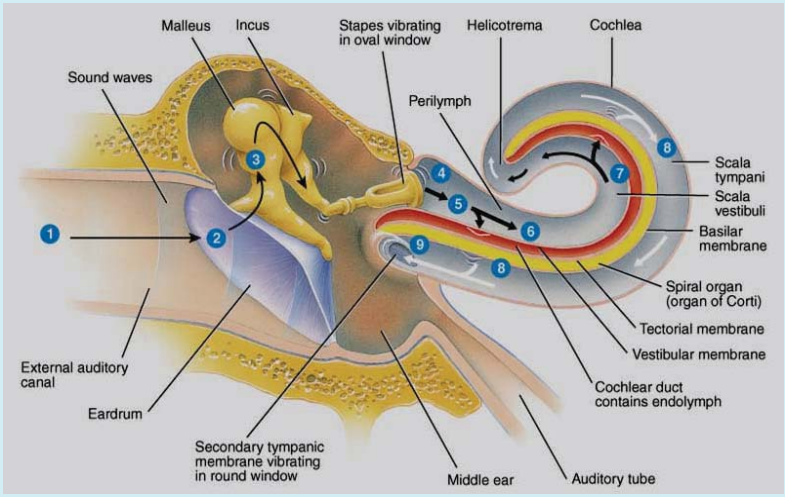
HOW IT ALL WORKS:

The transformation of vibrations in the air to sound in the auditory apparatus is thought to occurs as follows:

1. **Pressure waves in the air enter the External Ear**

2. **These travel down the External Auditory Meatus resulting in mechanical displacement of the Tympanic Membrane**

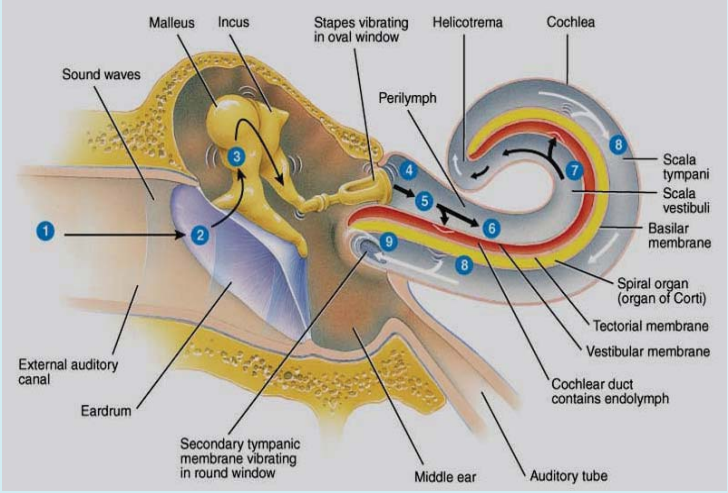
3. **Vibrations of the Tympanic Membrane are reduced in amplitude and increased in force by the mechanical leverage of the Ossicles a processes referred to as "Impedance Matching".**



4. **Vibrations are transferred from the Ossicles to the Oval Window, movement of the Oval Window induces a traveling wave in the perilymph of the Cochlear Canal that proceeds around the Scala Vestibuli -- through the Helicotrema -- down the Scala Tympani - pressure wave dissipates at the Round Window**

5. **As the pressure wave travels around the Scala Vestibuli and Scala Tympani, vibrational forces are transmitted to the Basilar Membrane.**

   Movement of the Basilar Membrane causes a "shearing motion" of the hair cell stereocilia with respect to the Tectorial Membrane



6. **Oscillations of the stereocilia of the sensory hair cells results in their depolarization, which results in the initiation of afferent impulse in the VIII nerve (spiral) ganglion cells in the Modiolus, which contact them**

7. **These peripheral neural impulses are transmitted via a variety of pathways to the auditory cortex of the CNS.**

CODING STIMULUS ATTRIBUTES OF SOUND:

1. Sound Amplitude:

Loud sounds produce a larger amplitude traveling wave that stimulates more hair cells on the basilar membrane

2. Sound Pitch:

2 theories of pitch encoding

A. Volley theory - the frequency of a sound vibration is encoded by the frequency of discharge of the 8th nerve afferents. for higher frequencies (>200 Hz) fibers fire in phase with the stimulus but different groups take turns skipping a volley.

B. Place Theory

Traveling waves caused by different sound frequencies -- "peak" in their displacement of the basilar membrane in different regions along the length of the cochlea.

-- **HIGH FREQUENCIES (20,000 HZ) = BASE**

-- **LOW FREQUENCIES (500 HZ) = APEX**

Prolonged exposure to loud sound of a given frequency results in degeneration of the hair cells and nerve fibers in that region of the cochlea.

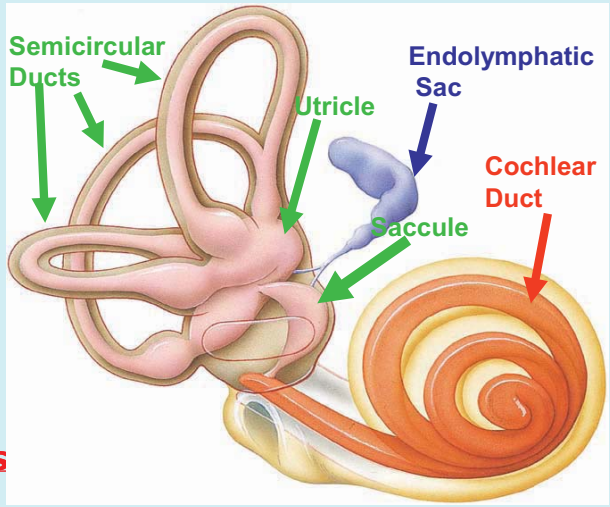
THE VESTIBULAR SENSORY APPARATUS

arises from the VESTIBULE portion of the bony labyrinth adjacent to the cochlear canal. They Consist of:

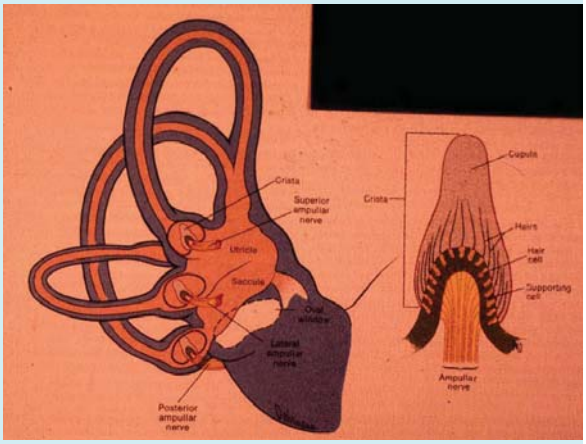
1. **Two endolymph-filled, membranous sacs, the UTICULE and SACCULE housed within the Vestibule of the Bony Labyrinth**

   -- the sensory epithelium in these membranous structures detect changes in head position and linear acceleration.

2. **Three, endolymph-filled membranous SEMICIRCULAR DUCTS (suspended within the bony semicircular canals) which arise from an expanded region of the Utricle called the AMPULLA.**



A semicircular duct is suspended within each semicircular canal and the 3 canals lie orthogonal to one another along the three planes of movement and are responsible for the detection of angular movement of the head.

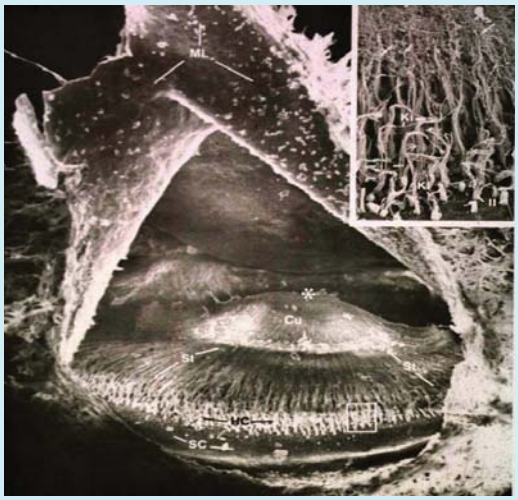


The ducts are part of the Membranous Labyrinth and thus composed of thin connective tissue walls lined by a simple squamous epithelium.

SEMICIRCULAR DUCTS & THE AMPULLA:

semi-circular ducts that connect to the Utricle at either end.

Each exhibits an expanded region known as the AMPULLA near one of its junctions with the Utricle.



The Ampulla of each semicircular duct contains a raised transverse ridge = CRISTAE AMPULLARIS which extends part way across the semicircular canal.

The epithelium of the Cristae is composed of 3 cell types

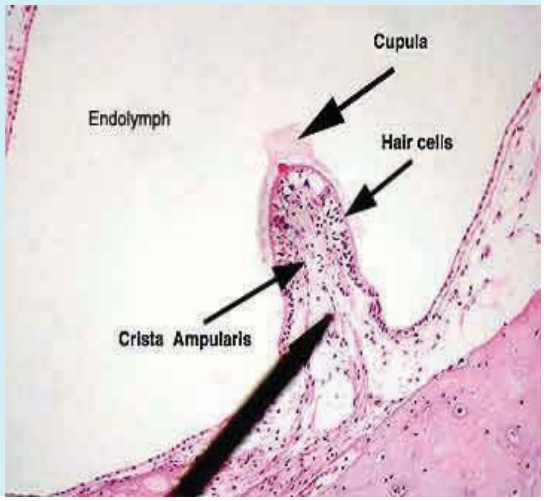
A. Tall columnar supporting cells = SUSTENTACULAR CELLS

B. Two types of SENSORY HAIR CELLS

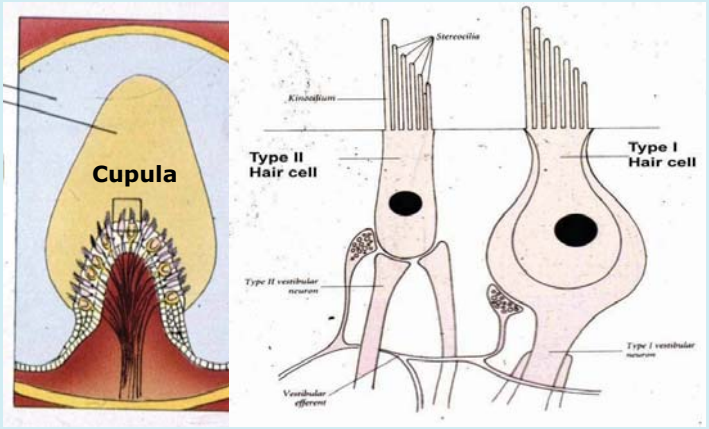
TYPE I:
-- Flask-shaped cells with apical stereocilia similar to the inner hair cells of the basilar membrane.

-- stereocilia are flanked by a single non-motile kinocilium

TYPE II:
-- cylindrical cells with apical stereocilia similar to outer hair cells of the basilar membrane. also possess kinocilia



Sensory hair cells receive contacts from neurons of the Vestibular (Scarpa's) ganglion located at the base of the modiolus.

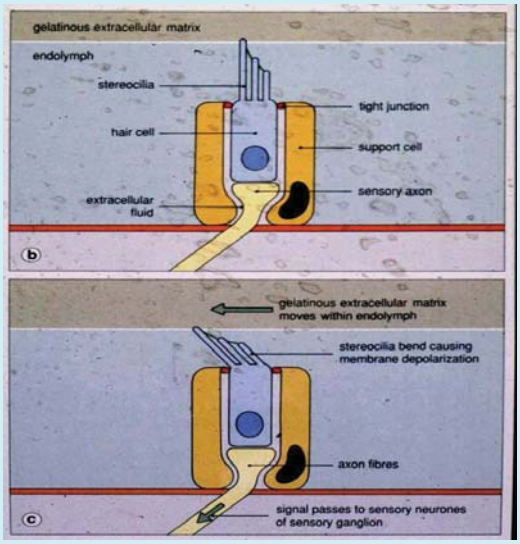


- **Type I cells - receive funnel- shaped (chalice) endings**
- **Type II cells receive bouton-like endings.**

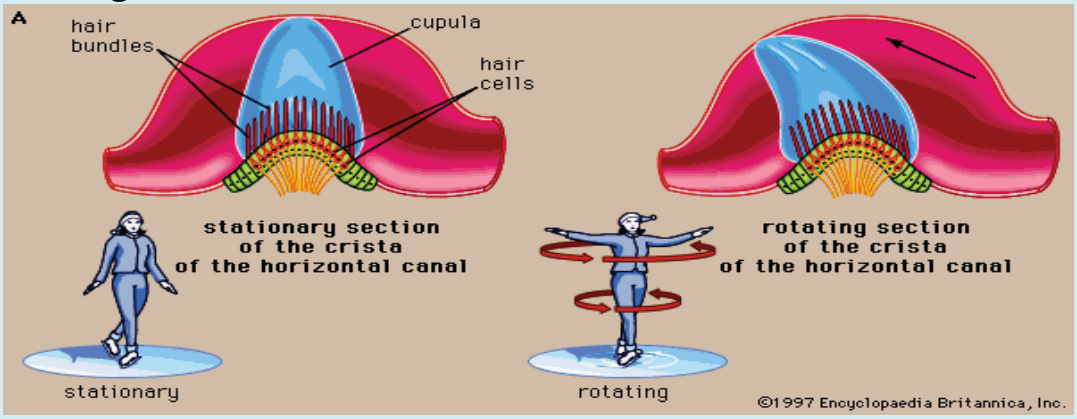
THE CENTRAL AXONS OF THESE GANGLION CELLS TERMINATE IN THE CNS IN THE VESTIBULAR NUCLEI OF THE BRAINSTEM.

The apical stereocilia of the sensory hair cells are embedded in a gelatinous glycoprotein material = CUPULA which extends like a hinged flaps from the walls of the ampullae .

- **Rotation or acceleration of the head in the plane of a given semicircular canal causes the stereocilia of the sensory hair cells to bend against the inertia of the endolymph and the Cupula.**



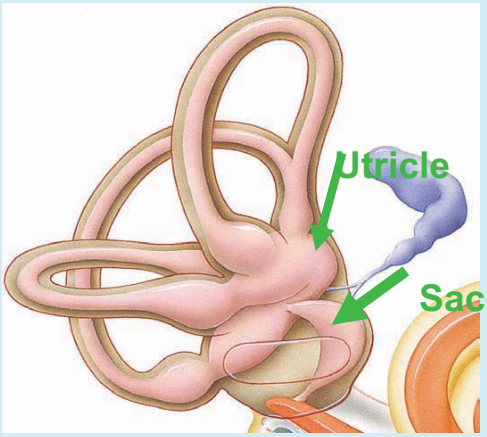
- **This results in depolarization of the sensory hair cells and initiation of action potentials in the Vestibular Ganglion cells**

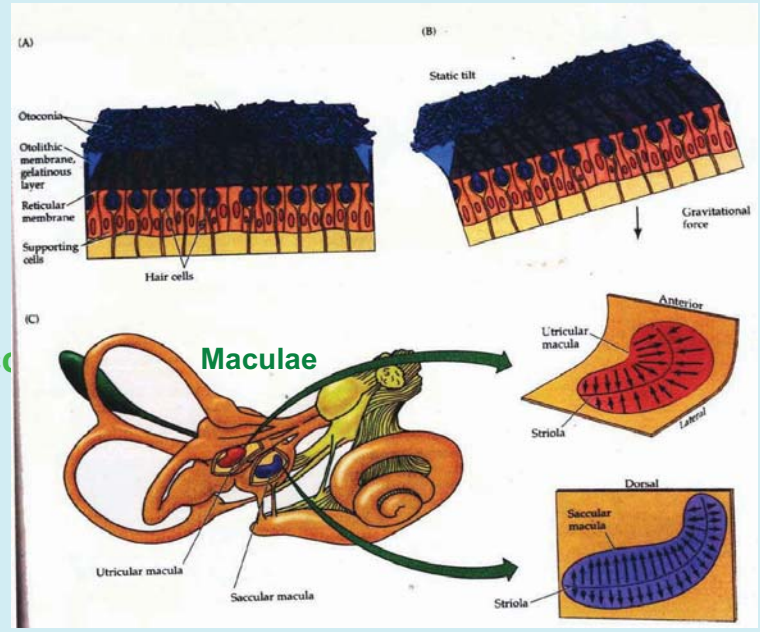


THE UTRICLE AND SACCULE:

- The Utricle and Saccule are housed in the vestibule of the bony labyrinth

- contain a small 3mm x 3mm patch of sensory epithelium called the Macula.





The Macula is responsible the detection of:

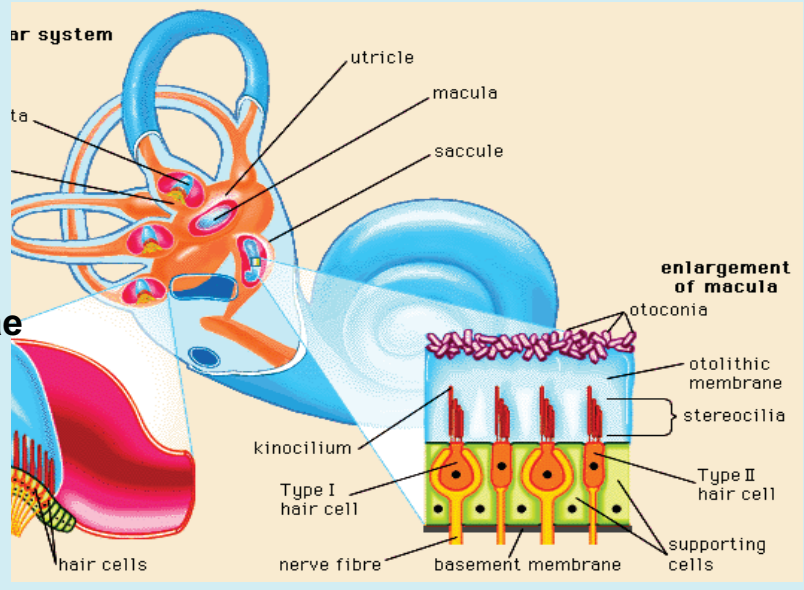
- head position with respect to gravity

- and linear acceleration of the head and body.

-- The macula of the saccule is oriented in the vertical plane
-- the macula of the utricle is oriented in the horizontal plane.

composed of 2 cell types:

1. columnar supporting cells
2. sensory hair cells similar to those found in the Cristae

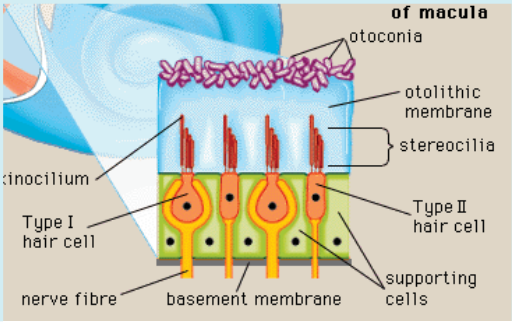


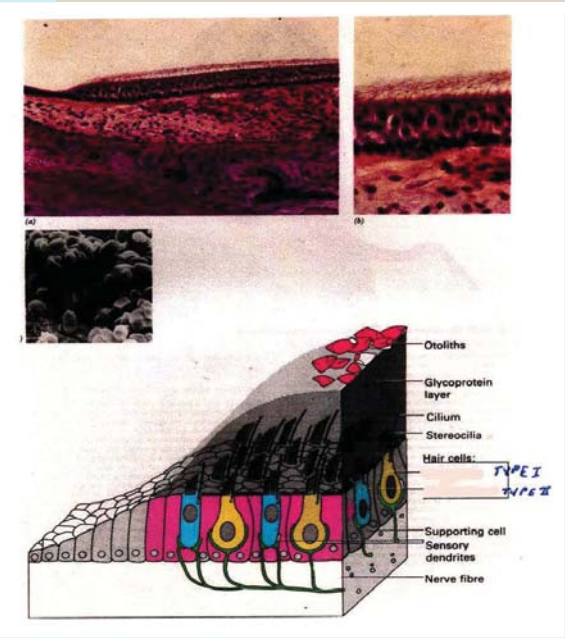
The apical surface of the sensory hair cells are covered by a gelatinous glycoprotein layer called the OTOLITHIC MEMBRANE

Suspended in the Otolithic Membrane are small (3-5 um) crystalline bodies composed of calcium carbonate called OTOLITHS

During tilt of the head with respect to gravity or linear acceleration..

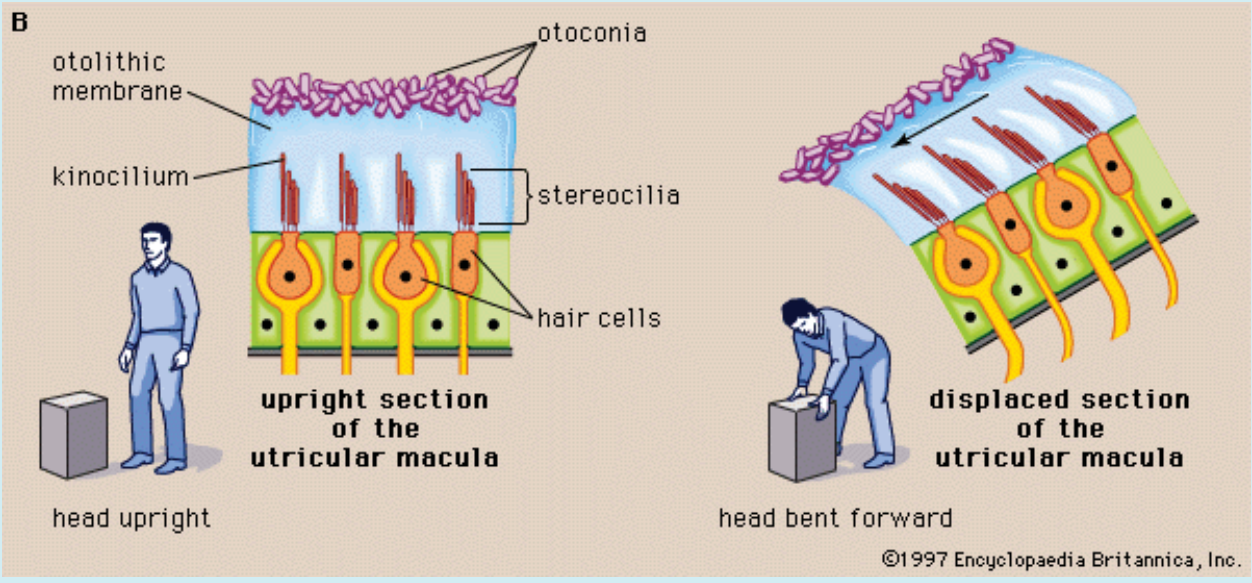
- **the inertia provided by the Otoliths in the Otolithic Membrane cause bending of the stereocilia of the hair cells.**





This generates a depolarization of the sensory hair cells and initiates action potentials in the Vestibular ganglion cells.

The central nervous system connections of the vestibular system are quite complex and will be studied in great detail next quarter in the neuroscience course.



THE STRUCTURE OF HAIR CELLS:

The basic structure of hair cells is similar throughout the auditory / vestibular apparatus

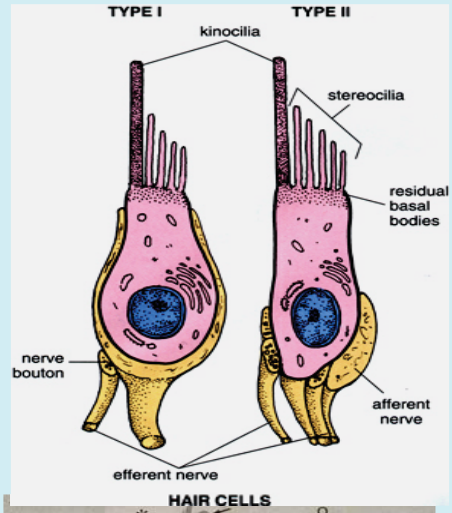
- regardless hair cell type (type I vs type II) or the organ in which they are found (basilar membrane vs macula vs cristae ampularis.

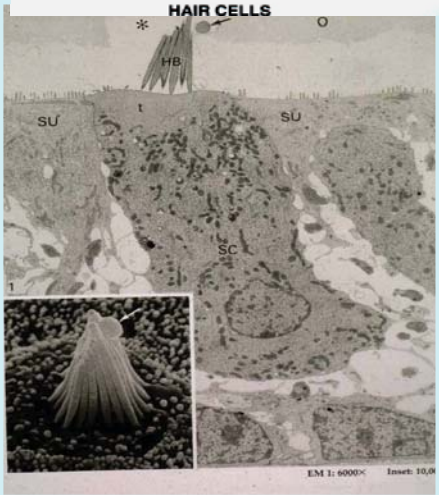
All share common features and mechanisms of action.

1. columnar cells capable of tranducing mechanical stimulation into electrochemical (nerve) impulses

2. stereocilia arranged hexagonally on the apical surface

   -- stereocilia are composed of actin filaments surrounded by paracrystaline structures which provided substantial rigidity.





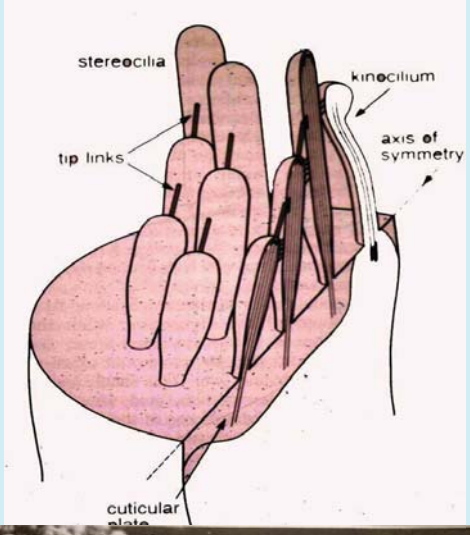
3. Stereocilia are graded in height with the tallest and shortest at opposite ends of the bundle.

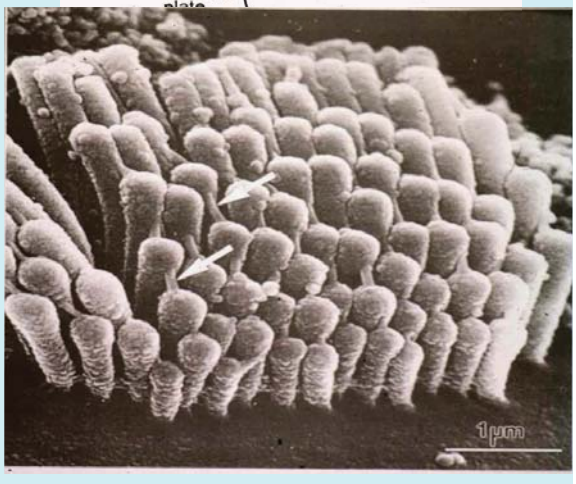
4. A true cilium called a KINOCILIUM is adjacent to the tallest row of cilia (except in the mammalian cochlea where kinocilium are lost soon after birth).

5. The tips of the stereocilia are extensively cross-linked by protein bridges called "TIP LINKS."

6. movement of the steroecilia produce depolarization of the hair cell cytoplasm.

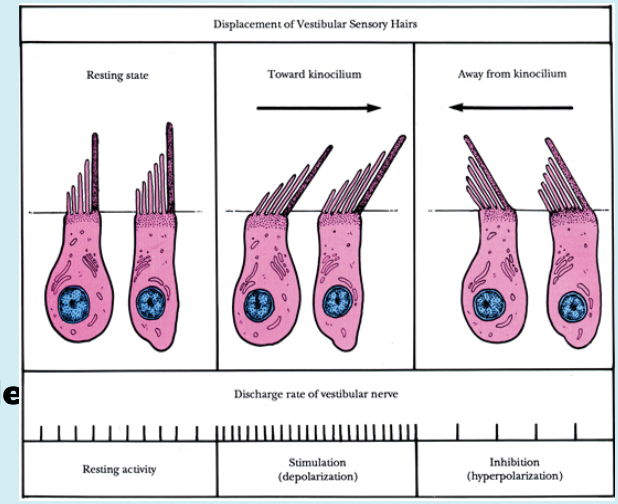
-- The orientation of the "TIP-LINKS" is such that they are at an extreme angle (nearly verticle) which provides for a unidirectional responsiveness of the cilia.





-- **Hair cell depolarization occurs when the cilia are bent in the direction of the tallest cilium which tightens the TIP - LINKS.**

  -- **Movement in any other direction loosens the tip-links and has no effect on the hair cells.**



— **The mechanism by which hair cell depolarization occurs following stereocilia movement must be fast enough to accomodate the rapid frequncies of vibration that the auditory/vestibular system is capable of responding to(> 1000 Hz).**

— **This rules out any potential second messenger gated ion channel apparatus in favor of a direct coupling of cilia with membrane ion channels.**

— **The location of the channels and the exact mechanism for their regulation is still not known.**

BLOOD SUPPLY OF THE EAR:

— **external ear - middle ear - bony labyrinth - served by vessels arising from branches of the external carotid artery**

— **The blood supply to the inner ear arises from the LABARYNTHINE ARTERY a branch of the basilar artery. The labarinthine artery divides to form:**

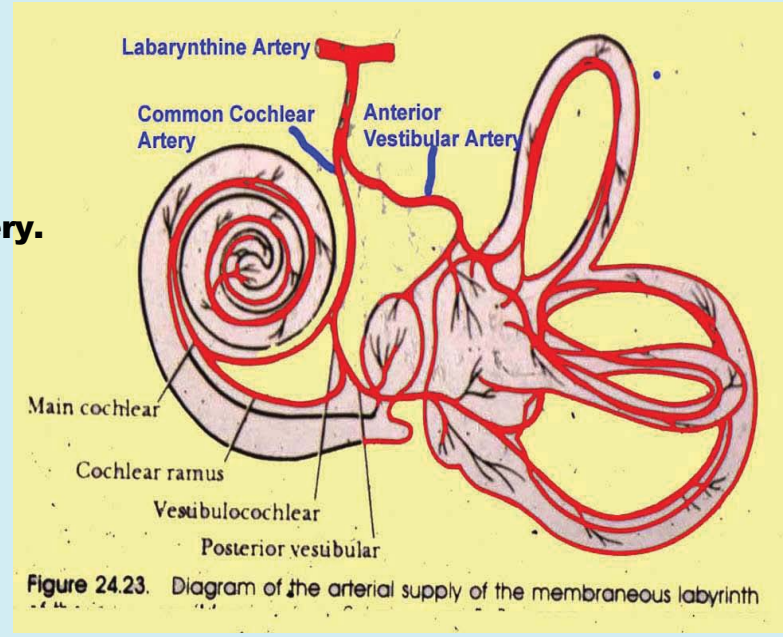


Figure 24.23. Diagram of the arterial supply of the membraneous labyrinth

1. **ANTERIOR VESTIBULAR ARTERY**
-- **supplies most of the semicircular canals**

2. **COMMON COCHLEAR ARTERY**
-- **supplies the Cochlea, Utricle and Saccule and the remainder of the Semicircular Canals**

— **Because the Hair cells of the auditory and vestibular apparatus have a very high metabolic rate. Interruption of blood flow in the labarinthine artery for even brief periods (minutes) can cause irreversible damage to these cells.**

DISORDERS OF THE EAR:

— **Clinically disorders of the ear are quite common particularly with advancing age.**

Loss of hearing most commonly results from:

1. **destruction of the hair cells or 8th nerve fibers in the cochlea.**

   -- **Hair cells (particularly type I) sensitive to a variety of antibiotics, diuretics, and salicylates**

— **chronic exposure to loud sounds of a constant frequency can result in the excitotoxicity of hair cells and the 8th nerve fibers which innervate them.**

2. **fixation or calcification of the ossicle**

3. **rupture or puncture of the tympanic membrane**

4. **Tumors of the 8th nerve or it's ganglion**

Vestibular dysfuction:

1. Drug toxicity - particularly certain antibiotics and diuretics

2. overproduction or blockage of endolymph circulation can result in abnormal stimulation of the vestibular and auditory hair cells .

   (MENIER'S DISEASE) and is characterized by intense debilitating vertigo, nausea, and vomiting as well as abnormal sound perception and sometimes temporary deafness.

3. Tumors of the 8th nerve or it's ganglion.